Calibration of the Pitot Tube

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CALIBRATION OF THE PITOT TUBE

A THESIS PRESENTED

By

Henry A. Dreffein

Edw. McBurney Jr.

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THE PITOT TUBE.

The object sought in this thesis is the determination of the constant (K) in the formula $V = K\sqrt{2gh}$, which applies to the use of the Pitot tube for determining the flow of gases; where V = velocity in feet per second, h = head in inches of water, and g = acceleration of gravity. The main features of the work are that the tubes were placed in a 23 3/4" pipe having a straight course of about 40' in either direction from the tubes, and that a large gas holder was used for measuring the volume of gas flowing through the pipe.

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The Pitot tube was invented by Pitot in 1730, its use being to measure the velocity of a stream of moving liquid. It consisted of a glass tube bent at right angles, one end of which was placed in the stream of moving liquid; so that it faced the direction of motion squarely; the orifice being less in area than the cross section of the tube. The impact due to velocity forced the liquid up the vertical portion of the tube to a height (h) above the surface of the liquid and gave a measure of the velocity according to the law $v = \sqrt{2gh}$.

Later on he added a second tube which was open at the bottom, the opening facing at right angles to the direction of flow. These tubes were also arranged so that they could be placed at any desired depth in the stream. This arrangement has since been used, generally, with modifications as to size of tubes and size and shape of nozzles.

It will be seen that in the above tubes the liquid in the bent tube will rise to a certain height due to the velocity head and pressure. In the straight tube there will be a head due to pressure alone. The difference in the heights of the liquid in the two tubes will be the head due to velocity alone.

Methods used to determine the flow of gases.

Pitot tubes have been used mostly in connection with water and most of the experimental work has been carried out along that line.

The most ancient form of instrument used for measuring the velocity of air is the anemometer. It has been in use since 1820, the present form of instrument having been perfected by Combes in 1838.

The anemometer is described in Carpenter's Heating and Ventilation on page 40. It is in brief a series of flat vanes

attached to an axis. The rotation of the axis causes motion of the hands of a counter proportional to the velocity of the air.

It was shown by Combes in 1838 that if (n) be the number of turns of the vane wheel and (a) and (b) are constants, the velocity of the air would be expressed by the formula

$v = a + bn$.

The principal objection to the anemometer is that continued use is liable to increase the friction of its working parts and cause a variation in the constants (a) and (b), which necessitates calibration from time to time.

It has been shown by experiment that results obtained by the measurement of the flow of air by means of this instrument are liable to be in error as great as 10 per cent.

Dr. A. Marx made exhaustive experiments on the measurement of flow of air, using anemometers. He also used an instrument which recorded pressure upon a plane disk placed in the current of air but did not use Pitot tubes, so far as we can learn. The article appeared in Gesundheits Engineer, Aug. 20, '04.

On page 41 Heating and Ventilation, Prof. Carpenter describes a Pitot tube arrangement for measuring the velocity of air in a pipe. He has the pressure tube and the velocity tube each attached to a separate manometer containing some fluid. He then states that by connecting one side of the manometer to the tube facing the current and the other to the tube entering at right angles, the reading will show directly the equivalent velocity head. This is roughly the form of Pitot tube now used in connection with the flow of gases.

A great many experiments have been performed to determine

the constant of a Pitot tube for water, but the experiments with air and other gases have been quite limited.

On page 45 of his Heating and Ventilation Prof. Carpenter gives reference to an investigation carried on by the Prussian Mining Commission in 1884. A large gas holder which contained over 70,000 cu. ft. was used. They arrived at the conclusion that the Pitot tube may be used with accuracy for measuring the velocity of air. The formula being $v = 66.7 \sqrt{h}$, v being the velocity in ft. per second and h being the head in inches of water.

Mr. M. S. Flinn A. I. T. '04 in his experimental thesis made a calibration of a Pitot tube of the simple form of curved velocity tube and straight pressure tube. He determined the constant of this tube to be .721. His apparatus consisted of a Westinghouse air compressor which was used to pump air into a receiver, which in turn supplied air through a previously calibrated gas meter to a 2" pipe in which the Pitot tubes were inserted.

In June 1904 Mr. Flinn also made an experiment at the Peoples Gas Light and Coke Company's plant, where our experiments were also carried on. He used a large holder of three sections having a diameter of about 180', the height of each section being about 42'. He determined the constant to be .509. The Pitot tubes, however, were placed in a bend of the pipe and it is probable that swirls and eddy currents existed which would effect the reliability of the gauge readings.

In the American Gas Light Journal of April 18, 1904 is an article from a paper read by Mr. Richard Threlfall at a meeting of the English Institution of Mechanical Engineers. It gives

an account of the calibration of Pitot tubes with a gas holder, and of the determination of the radius of the circle which is the locus of points through which the stream has the mean velocity. The mean velocity being defined as that velocity which, when multiplied by the area of section of the pipe, will give the delivery. The radius of this circle was found to be about .775 of the radius of the pipe. The error of the gauge was estimated in per cent of true delivery and was found to average 1.38% low.

In a paper by W. B. Gregory A.S.M.E. Vol. 25, Dec. 1903 No.015, a great many different forms of Pitot tubes are described and illustrated. The tubes here being used for water. The tubes used in our experiments were modeled somewhat after No.9 of these tubes.

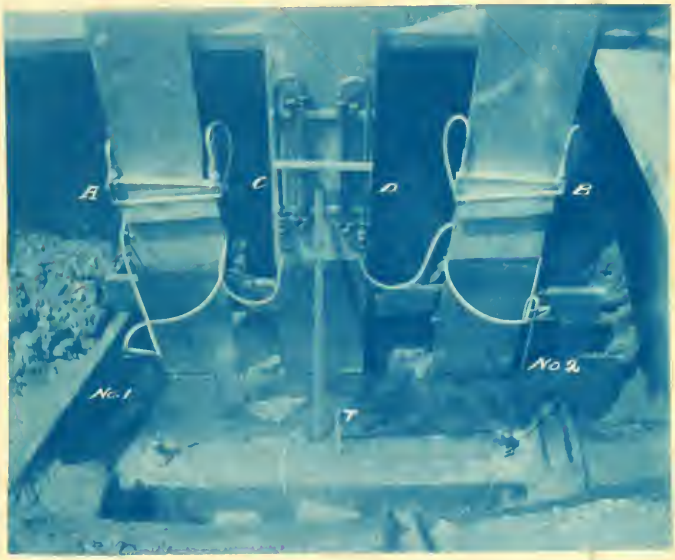
Mr. Gregory states that the instrument has also been used to measure velocities of air in a series of tests of the greatest refinement conducted by Capt. W. Taylor, U.S.N., at the Experimental Mode, Basin, Washington Navy Yard.

The above are some of the important experiments performed with Pitot tubes for the flow of gases and lead up to the investigations of this thesis.

Location and General arrangement:-

The investigation was carried on at the works of the Peoples Gas Light & Coke Company at Division St. and Elston Ave. The following photograph shows the holder that was used. The bottom section is 16750 sq. ft. in cross section and the top section 16290 sq. ft. The holder has a total height when full of about 60 ft.

A 23 3/4" pipe leads from this holder at the point 'A'.


A
C
D
B
No. 1
No. 2
T

At the point 'B' the pipe is about 5 1/2 ft. below the surface and a large hole was here made in which to set up the apparatus. A long table of heavy plank was set up across the hole parallel to the pipe and three upright boards driven in the ground near the pipe and nailed to the table at the top. The table being secured at the top and the boards braced at the middle and bottom gave a very secure frame on which to set up the gauges. The table and the part of the boards projecting above ground may be seen in the photograph at 'B'.

The following photograph gives a view of the Pitot tubes and gauges set up in working order. The gas main is 23 3/4" in diameter and at this point the top of the pipe is about 5 1/2' below the ground. This accounts for the apparatus being surrounded by banks of clay on all sides.

The weather during the experiments was quite rainy and gave considerable trouble by water draining into the hole, sometimes to a depth of 3 or 4 feet between experiments. However, a small hole was dug at one end of the large hole which was deeper than any other part and the water was kept bailed out of this hole thus keeping the surface of the pipe dry during an experiment.

Tube marked (No.1) is nearest the holder and (No.2) is four feet from No.1. The thermometer for measuring the temperature of the gas is at (T) midway between the two tubes. Ames differential draft gauges were used for obtaining the velocity heads. They are seen at (A) and (B). Gauge marked (A) is for tube No.1 and B for No.2. The rubber tube leading to the left hand end of the gauge (the larger end) is from the pressure tube; the rubber tube leading to the right hand or small end of

A
B

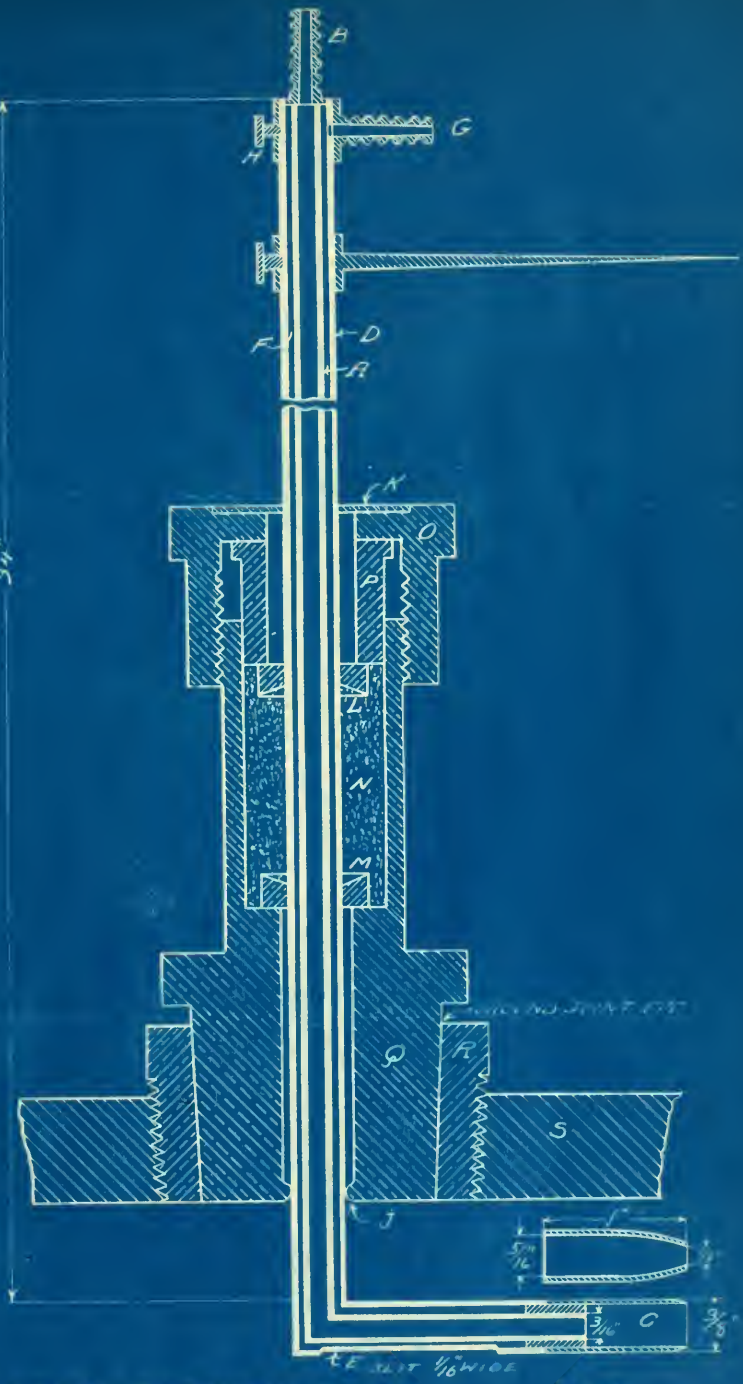
the gauge is from the combined pressure and velocity tube.

The pressure gauges are at C and D, C is for No.1 and D is for No.2. C is connected to the velocity tube of No.1 and registers the velocity plus the pressure heads. D is connected to the pressure tube of No.2 and registers the pressure head.

The Pitot tubes are placed in stuffing boxes and can be moved diametrically across the pipe. By means of the pointer seen near the top of the tube and a scale held on the pipe perpendicular to it the nozzle can be placed at any desired distance from the center of the pipe.

The pointer was previously set parallel to the horizontal bottom part of the tube (i.e. the part containing nozzle), and marks made on the cap and tube to make sure it remained in position. The direction of the nozzle could then be determined by the direction of the pointer.

The accompanying drawing shows a section taken through the center line of one of the tubes and stuffing box. The inside tube (A) is 3/16" outside diameter and is 1/32" in thickness of metal. This is the combined velocity and pressure tube. The rubber tube leading to the Ames draft gauge is attached at (B): the tube receives the pressure due to velocity and static head at the nozzle (C). The pressure tube D surrounds the velocity tube: it is 3/8" outside diameter and the metal is 1/32" in thickness. The pressure is admitted through the slot E in the bottom of the horizontal part of the tube. This slot is 1 1/4" long and 1/16" wide. The pressure is exerted through the annular space (F) between the two tubes. The rubber tube leading to the pressure side of the differential gauge and to the U tube is attached at (G). This attachment is made by means



SECTION THROUGH PITOT TUBE AND STUFFING BOX

SCALE FULL SIZE

of a snug fitting cap (H) held in place by a set screw. This cap can be removed so that the tube may be removed from the stuffing box.

The nozzle (C) is also detachable in order that other shapes may be used. The other nozzle used is shown at (I). Nozzle C was used on tube No.1 and Nozzle I mostly on tube No.2.

In regard to the stuffing box it is seen that the tube fits snugly in stuffing box proper at the bottom point (J) and the top at K. Through the rest of the box the tube is allowed some play, more near the top than at the bottom. At K is a little circular plate the hole through which the tube passes being eccentric. By turning this plate the tube will be moved out of line, as it were, with the stuffing box. This design was made in anticipation of the holes in the gas main being drilled not quite perpendicular to the pipe. Before boring the hole in plate K a trial was made for alignment and it was found necessary to make the holes as eccentric as the play allowed in the top part of the box would permit. The rings L and M fit snugly on the tube but can move with the tube through the packing space N. By screwing down the cap (O) the bushing P presses down on the ring L and compresses the packing. Q is a ground joint having a taper of 1/2" to the foot and fits in the bushing R which is screwed into the pipe S. By this ground joint arrangement the apparatus consisting of Pitot tube and stuffing box can be put in place or taken out in a few seconds time, thus eliminating inconvenience from the escaping gas. When the tubes were removed for over night the stuffing boxes were replaced by brass plugs with the same ground joint fit. The plugs were further secured by small set screws in the side.

Method of Procedure.

Calibration of Gauges:-

Before making any runs the Ames differential gauges, to be used for obtaining the velocity heads, were accurately calibrated. The differential gauge was set up and connected by rubber tubing and a tee connection to a U shaped pressure gauge so that a pressure could be exerted simultaneously in both gauges.

A cathetometer was set up a few feet away and the difference in level of the liquid in the branches of the U tube accurately read for different pressures produced in the differential gauge. The Ames gauges were found to be practically correct for the liquid furnished by the manufacturers. This liquid should have a specific gravity of .837.

The results of this calibration are as follows:

Gauge reading.	Cath. Reading.		Difference
.20	34.643	35.246	.598
.30	35.370	34.484	.886
.40	34.330	35.530	1.210
.50	35.730	34.168	1.562
.60	34.050	35.827	1.777
1.00	36.514	33.460	3.054
1.00	36.500	33.442	3.058

$\frac{12.145}{4}$ = 3.036 cm.

1" gauge reading is equivalent to 3.036 cm. = 1.194 inches.
1 ÷ 1.194 = .837 the specific gravity of the liquid which must be used in the gauge if it is to read in inches of water.

In all of the gauges kerosene with a specific gravity of

.807 was used. Hence all Ames gauges readings are $\frac{.857}{.807} = 1.038$ too high and must be corrected by this factor to give inches of water. The manometer readings must be multiplied by .807 to give inches of water.

Method of making a run:-

Runs could be taken with the gas flowing in either direction; either into or out of the holder. To measure the rise or fall of the holder a steel tape graduated to hundredths of a foot was fastened by a long hook to the railing at the top of the holder. Readings were taken by means of a long tram held on a stationary point at the foot of the holder. When the bottom section of the holder was at its lowest position and the upper section moving alone, the tram was held on the top of the bottom section.

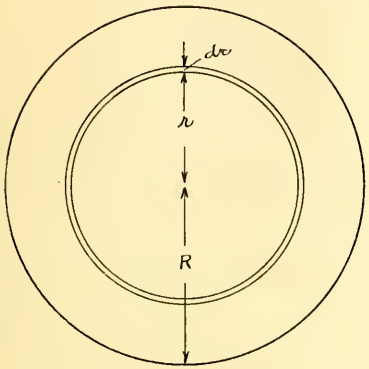
In general the method of manipulating the tubes was to keep one tube with the nozzle in the center of the pipe and to move the other tube across the pipe from center to edge, taking readings every 1/2 inch from the edge, for about three inches then every inch until within 4 or 5 inches of the center, and finally every 2 inches until center was reached.

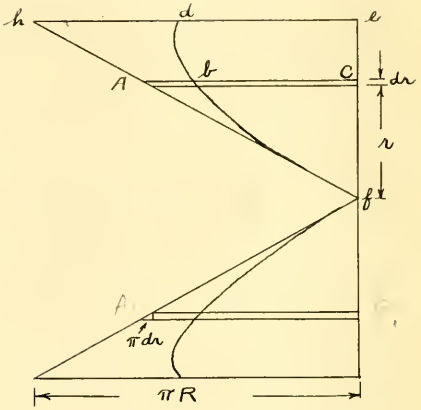
Readings on the holder were taken about every 5 minutes and readings of the differential gauges as often as expedient. Readings of the pressure gauges were taken once or twice for every run.

Method of Calculation.

Since velocities vary so greatly at different sections of the pipe some method had to be devised for obtaining the quantity of gas flowing from knowing the velocity heads at the different sections.

Let the following circle represent a cross section of the pipe. Take a ring of inside radius 'r' and of width dr. Then the area of this ring is





$$\text{Area} = \pi (r + dr)^2 - \pi r^2$$

$$\text{Area} = \pi (r^2 + 2rdr + dr^2) - \pi r^2$$

$$\text{Area} = 2\pi rdr + \pi dr^2$$

The area of this circle can also be represented by the figure on the right. The area of a circle is πR^2. If he = πR, then the area of the two triangles = $2 \times \frac{\pi R \times R}{2} = \pi R^2$. It was shown that the area of a ring is $2\pi rdr + \pi dr^2$. By projecting and cutting two laminae from the figure we get two areas A C and A_1C_1. The inside edge of A C is πr in length. From the figure it is easy to see that the area of the two laminae is $2\pi rdr + \pi dr^2$, the area of the ring.

If the velocity of the gas is uniform at all points in

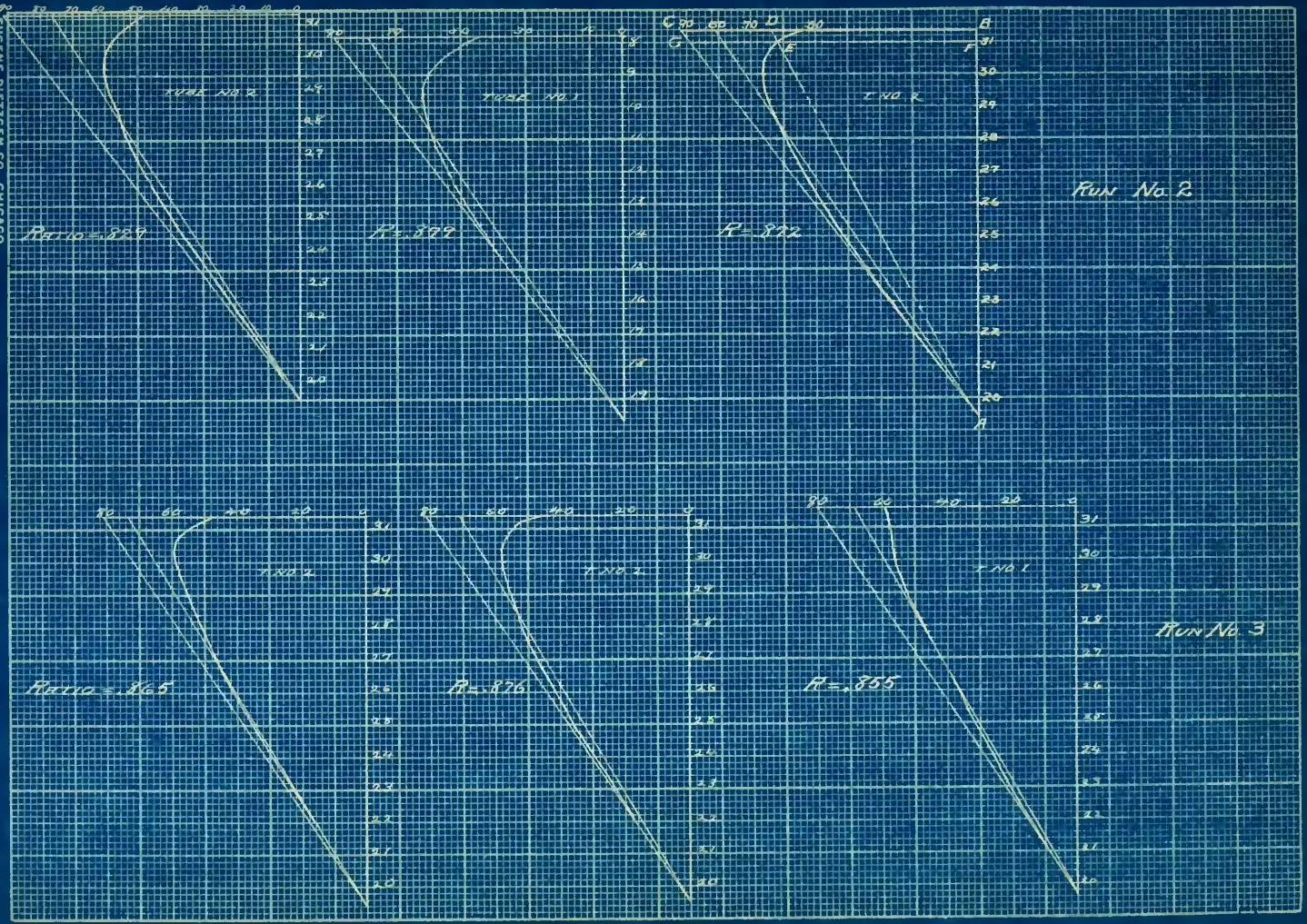
the pipe, then the quantity which passes any section in a unit of time is proportional to the area of that section and therefore the area of the figure is proportional to the quantity of gas passing through, per unit of time. We have, however, found that the velocity is not uniform but varies with the distance from the center, the velocity being assumed to be the same throughout any annular ring of width dr. We know that the quantity is proportional to the velocity. Hence if we know the velocity at any point "C" at a radius of r from the center and the velocity at the center, then if B is such that B C ÷ A C = vel. at C ÷ vel. at center, the area of the portion of the laminae B C is to the portion A C as the actual quantity which flowed, is to the quantity which would have flowed if the velocity were the same at C as at the center. If these conditions are known for all points in the pipe then the curve dbf will result and the area of dbfe ÷ hef = actual quantity ÷ the quantity which would have passed if the velocity were the same at all points as at the center. But the actual quantity of gas flowing in a unit of time can be found from the holder displacement. Therefore, the quantity which would have flowed if the velocity were the same at all points as at the center, can be found by dividing by means of this figure. Knowing the sectional area of the pipe and the quantity which would have flowed, the velocity at the center can easily be found dividing the latter by the former.

We know that the velocity of a gas is proportional to $\sqrt{h}$, and since in this part of the work we are concerned only with the ratio of velocities, the actual velocity need not be known to draw the curve dbf and the square root of the gauge

readings can be used instead. It is also evident that since we are only concerned with the ratio of the two areas one triangle need only be drawn, also the ratio of the areas will be the same no matter what scale be used. For example take the third curve of run No. 2. A B represents the radius of the pipe, C B the $\sqrt{H}$ at the center and is .918. With the tube placed at the radius marked 31, $\sqrt{H}$ = .632 = B D in the figure. D A is now drawn which intersects the radius marked 31 at the point E. In this way all points were located. It is easy to see from the construction that E F : F G = $\sqrt{H \text{ at } 31}$: $\sqrt{H \text{ at center}}$. In this case the area under the curve : area of the triangle = $\frac{3.00}{3.40}$ = .872.

As was explained above tube No.1 was held at the center while tube No.2 was varied in position. It was found that both read practically the same while at the center and therefore it was assumed that both would read the same at all points. Therefore, the average $\sqrt{H}$ at the center with No.1 during the time taken to get a set of readings for all positions from center to edge with No.2 was taken to be the $\sqrt{H}$ at the center for this particular case. In nearly all cases two or three such sets of readings were taken for each run and curves were drawn for each set. The ratio of the area under the curve to the area of the whole triangle was found for each curve and the results were plotted with these ratios as ordinates and $\sqrt{H}$ as abscissae. From the resulting curve the values of the ratio, of the actual quantity which flowed to the quantity which would have flowed if the velocity were uniform throughout, were obtained in making the calculations for the entire run.

Run No. 1.



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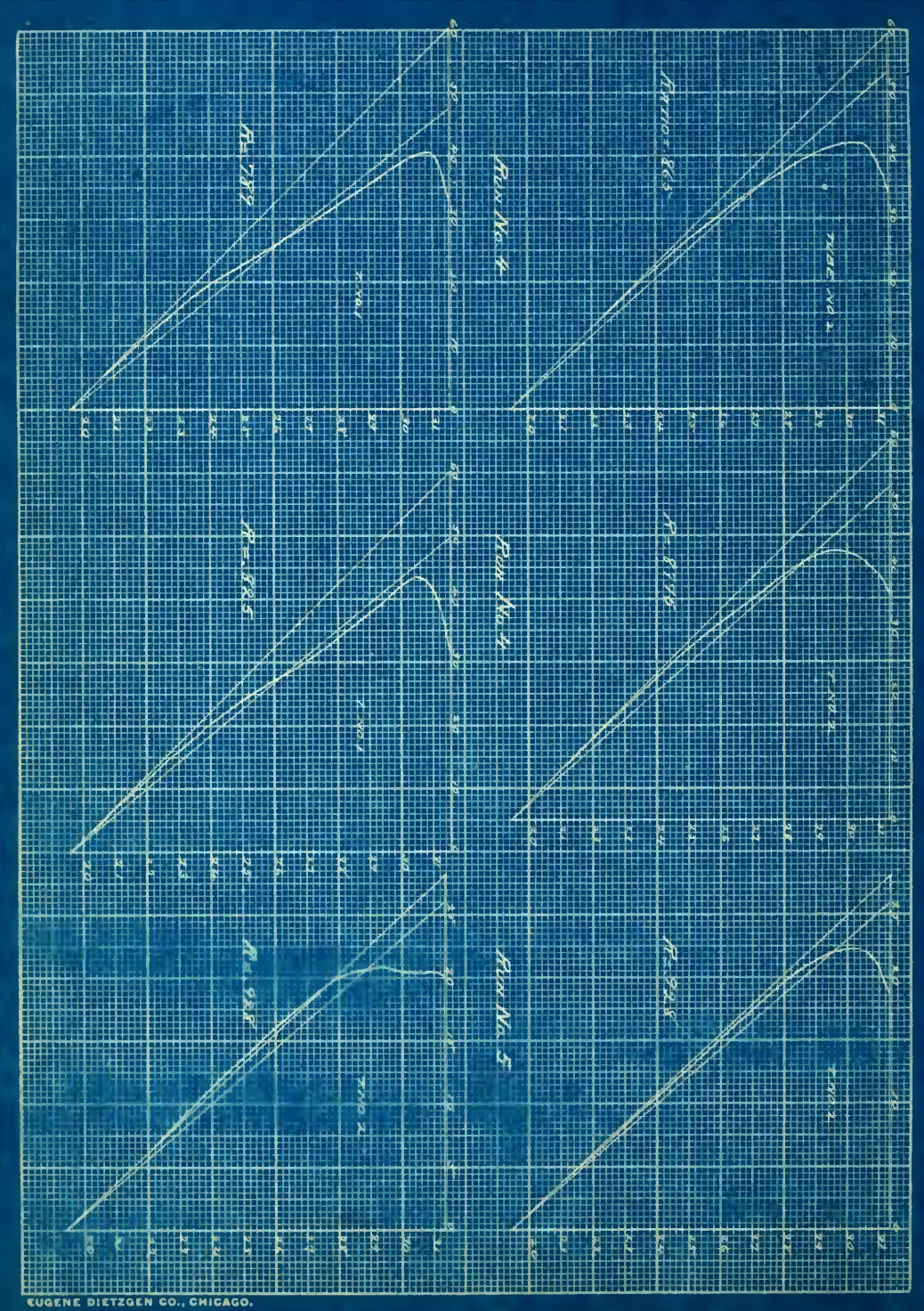

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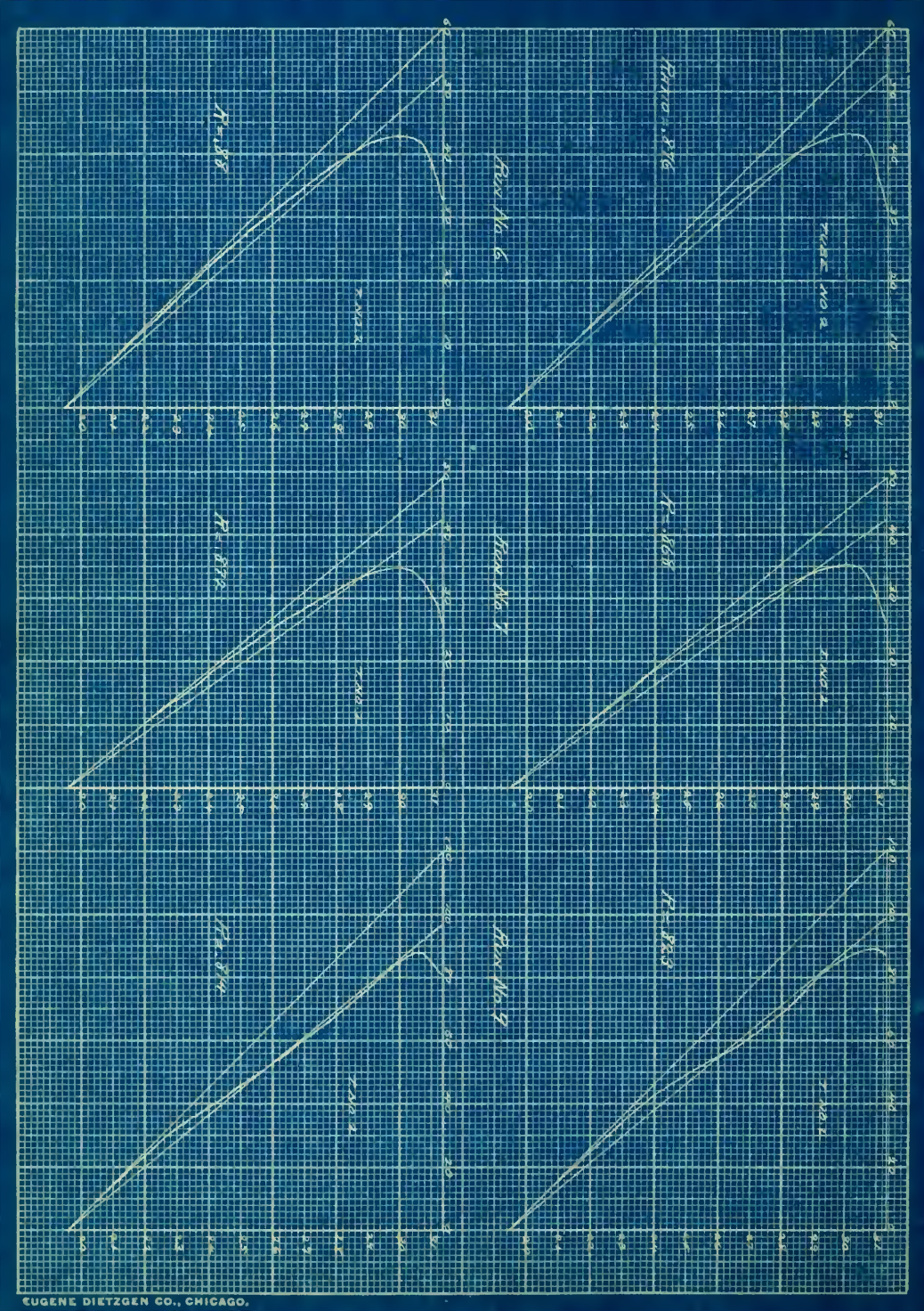

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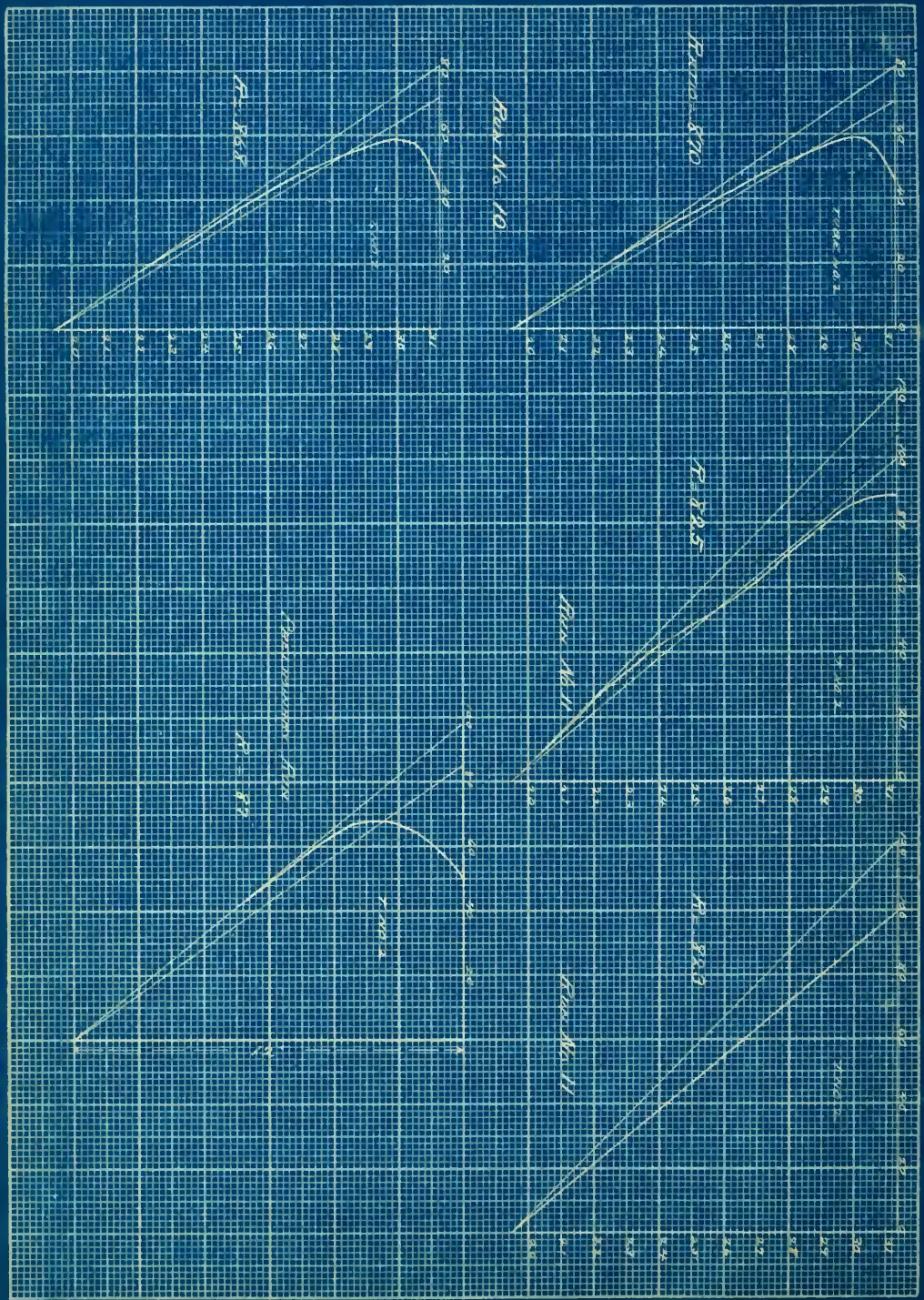

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Run No.1.

The first run was on May 20th, and was merely in the nature of a preliminary run to determine if everything was satisfactory in regard to arrangement of apparatus etc.

An exhauster was used to draw the gas from the holder, giving a high velocity of about 78 feet per second. Quite large and rapid vibrations occurred in the differential gauge readings, due to the pulsations of the exhauster. The run was taken through the entire two sections of the holder and some variations in gauge readings occurred when the upper section uncupped from the lower section. It was therefore decided to confine a run to one section of the holder only. In case the entire holder be filled or emptied continuously two separate runs would be considered. This being a preliminary run no attempt was made towards refinement and the calculations are not carried out here.

Analysis of gas for May 23rd.

Analysis by volume

$C O_2$	Illuminants	O	C O	H	$C H_4$	N_2
5.40	13	.8	26.8	28.62	19.44	.594

Wts. of 1 cu. ft. at 68° F. and 30" mercury

.1150	.0741	.0831	.0729	.00523	.0418	.813

$C O_2$	5.40	x .1150	=	.6205
Ill.	13.0	x .0741	=	.964
O	.80	x .0831	=	.0665
C O	26.80	x .0729	=	1.951
H	28.62	x .00523	=	.1499
$C H_4$	19.44	x .0418	=	.813
N_2	5.94	x .0730	=	.433
Wt. of 100 cu. ft.			=	4.9979 lbs.

Barometric pressure 29.66 inches of mercury.

Run No. 2.

This run as well as runs No.3 and No.4 was taken on May 23rd. The upper section of the holder was used with the gas flowing into the holder. The gas was always run from one holder to another, the secondary holder being the larger and heavier one of three sections so that different velocities could be obtained by varying the valve opening. All measurements were taken on the two section holder.

For a part of the time during this run tube No.2 was kept at the center of the pipe and tube No.1 varied in position, and part of the time No.1 was kept at center and No.2 varied. The day was rather cool and cloudy and as the runs were taken near mid-day at which time expansion of the gas in the holder due to the sun's heat is always small, it was here neglected.

Calculations Run No.2.

$$\text{Pressure in holder} = \frac{5.1 \times .807}{13.6} + 29.66 = 29.96\text{" mer.}$$

$$\text{" " pipe} = \frac{6.3 \times .807}{13.6} + 29.66 = 30.03\text{" mer.}$$

5.1 and 6.3 being the pressures in inches of kerosene, .807 the correcting factor for the kerosene as previously explained, 13.6 the specific gravity of mercury and 29.66 the barometric pressure.

The wt. of one cu. ft. of gas in the pipe =

$$.04998 \times \frac{528}{520} \times \frac{30.03}{30.00} = .0508$$

$\frac{528}{520}$ being the correcting factor for temperature and $\frac{30.03}{30.00}$ for pressure between holder and pipe.

Fig. 2 - nat. schedule

Now $v = \sqrt{2gH}$, where H = head in ft. of gas and

$$v = \sqrt{2 \times 32.16 \times \frac{62.4}{.0508} \times \frac{1}{12}} \times \sqrt{h}$$

where h = the head in inches of water, 62.4 the wt. of one cu. ft. of water and .0508 the wt. of one cu. ft. of the gas in the pipe. Solving

$$v = 81.15 \sqrt{h}$$

Velocity head in inches of water

$h = \frac{.828}{1.038} = .798$ inches of water, where .828 is the average velocity head, with inches of kerosene found by squaring the average $\sqrt{H}$ for the run, and 1.038 is the correcting factor for the differential gauge readings as previously explained.

$$\therefore \quad v = 81.15 \sqrt{.798} = 72.5$$

the theoretical velocity in ft. per second.

Now the average rise of the holder in ft. per minute was .738 and the upper section has an area of 16290 sq. ft.

$$\therefore \quad \frac{.738 \times 16290}{60} = 200.5 \text{ cu. ft. per second.}$$

the actual volume flowing into holder.

Correcting this for pressure in the pipe we have

$200.5 \times \frac{29.96}{30.03} = 200$ cu. ft. per second through the pipe, and $\frac{200}{.870} = 230$ the apparent cu. ft. per sec., where .870 is the ratio taken from the curve of actual to theoretical discharge previously explained. Also $\frac{230}{3.08} = 74.7$ ft. per second, the actual velocity at center of pipe, where 3.08 is the area of cross section of the pipe in sq. ft.

Dividing the actual velocity by the theoretical velocity will give the constant of the tube to be used in the formula $v = K \sqrt{2gh}$ $\quad \therefore \quad \frac{74.7}{72.5} = 1.030$ Constant.

Calculations Run No. 3.

Pressure in holder = $\frac{6.6 \times .807}{13.6}$ + 29.66 = 30.05 inches of mercury

Pressure in pipe = $\frac{7.6 \times .807}{13.6}$ + 29.66 = 30.11 inches of mercury.

The wt. of one cu. ft. of gas in the pipe at a temperature of 60° F. and a pressure of 30.11 ins. of mer. is

$$.04998 \times \frac{30.11}{30.00} \times \frac{528}{520} = .0508 \text{ lbs.}$$

$$v = \sqrt{2gH} = 81.1 \sqrt{h}$$

average h = .638 ins. with kerosene

" " = $\frac{.638}{1.038}$ = .615 ins. of water

$\therefore$ v = 81.1 $\sqrt{.615}$ = 63.55 ft. per second, the theoretical velocity.

Average rise of holder was .622 ft. per second and lower section was in use its area being 16750 sq. ft.

$\therefore$ $\frac{.622 \times 16750}{60}$ = 173.6 cu. ft. per second the actual volume passing into holder. Correcting for pressure in pipe

$173.6 \times \frac{30.05}{30.11}$ = 173.2 cu. ft. per second through the pipe.

Ratio from diagram is .872

$\therefore$ $\frac{173.2}{.872}$ = 198.9 apparent cu. ft. per second.

$\frac{198.9}{3.08}$ = 64.5 ft. per sec. actual

$\frac{64.5}{63.55}$ = 1.014 Constant.

Run No. 4.

Runs 2, 3 and 4 were all made on May 23rd. After run 3 the gas was rapidly exhausted from the lower section of the holder and for run No.4 was allowed to flow back into the holder. The bottom section was used for this run.

As may be seen on the data for this run several readings were taken at varied positions for each tube. It was noticed during the first part of this run that both differential gauges read the same when their nozzles were placed at the center of the pipe but during the latter part of the run No.2 gauge read about .02" lower than differential gauge No.1.

Calculations Run No.4.

Pressure in holder = 30.05 ins. of mercury

" " pipe = 30.05+ ins. of mercury.

$.04998 \times \frac{528}{521.5} \times \frac{30.05}{30.00} = .0507$ lbs. wt. of one cu. ft. of gas in the pipe.

$$v = \sqrt{\frac{2 \times 32.16 \times 62.4}{12 \times .0507}} \times \sqrt{h}$$

$$v = 81.1 \sqrt{h}$$

Average velocity head = .355 ins. with kerosene

$h = \frac{.355}{1.038} = .342$ ins. of water.

$v = 81.1 \sqrt{.342} = 47.45$ ft. per sec. theoretical.

Average rise of holder .450 ft. per min.

$\frac{.450 \times 16750}{60} = 125.6$ cu. ft. per second actual volume passing into holder.

$125.6 \times \frac{30.05}{30.05+} = 125.6$ cu. ft. per second in pipe.

Ratio from curve = .875

$\frac{125.6}{.875} = 143.5$ cu. ft. per second apparent flow.

$\frac{143.5}{3.08} = 46.6$ ft. per second actual velocity at center.

$\frac{46.6}{47.45} = .984$ constant of tube.

Analysis of Gas for May 25th.

Constituents	Volume	Wts.
C O_2	5.20 x .1150	= .5980
Illuminants	13.80 x .0741	= 1.0220
O	.60 x .0831	= .0499
C O	26.40 x .0729	= 1.922
H	32.40 x .00523	= .1694
C H_4	17.28 x .0418	= .7210
N_2	4.32 x .0730	= .3158
		4.7981 lbs.

the weight of 100 cu. ft. at 68° F and 30 ins. of mercury. Barometric pressure 29.22 inches of mercury.

Run No. 5

This was the first run made on May 25th. It was taken with the gas flowing into the upper section of the holder. Tube No.1 was kept at the center of the pipe throughout the run, No.2 being varied in position.

About this time calibrations were made for expansion of gas in the holder due to the heat of the sun. The following readings were taken

66.27' at 11:25 A.M.

66.68' at 11:45 A.M.

giving a rise of the holder of .041 ft. in 20 minutes or .002 ft. per min. Now the average rise of holder during the run was .252 ft. per min. Therefore, the rise due to the entrance of gas alone was .252 - .002 = .250 ft. per minute.

Calculations, Run No.5.

Pressure in holder = $\frac{5.1 \times .807}{13.6}$ + 29.22 = 29.52" mer.

Pressure in pipe = $\frac{5.2 \times .807}{13.6}$ + 29.22 = 29.53" mer.

.0480 x $\frac{528}{524.5}$ x $\frac{29.53}{30.0}$ = .0476 lbs. wt. of 1 cu. ft. in pipe

$v = \sqrt{\frac{2 \times 32.16 \times 62.4}{12 \times .0476}} \times \sqrt{h} = \sqrt{7015}\ \sqrt{h} = 83.8\ \sqrt{h}$

Average velocity head was .0787 ins. with kerosene

or $\frac{.0787}{1.038}$ = .07585 ins. of water.

$v = 83.8\ \sqrt{.07585}$ = 23.05 ft. per second theoretical

$\frac{.250 \times 16290}{60}$ = 67.9 cu. ft. per sec. actual flow into holder.

Ratio from curve is 92.7

$\frac{67.9}{92.7}$ = 73.2 cu. ft. per sec. (apparent)

$\frac{73.2}{3.08}$ = 23.77 ft. per sec. at center actual velocity.

$\frac{23.77}{23.05}$ = 1.030 Constant.

Run No.6.

This run, made on May 25th, follows directly after run No.5, that is, the gas is still entering the upper section of the holder. Tube No.1 was kept at the center of the pipe as before and No.2 varied in position.

Directly after this run the holder was again calibrated for expansion the readings being as follows:

21.872' at 12.25 P.M.

21.90' at 12.55 P.M.

giving a rise of .0009' per minute.

Correcting the average rise of .489 ft. per min. by this amount we have a rise of .488 ft. per min.

Calculations, Run No.6.

Pressure in holder = $\frac{5.1 \times .807}{13.6}$ + 29.22 = 29.52 ins. mer.

Pressure in pipe = $\frac{5.6 \times .807}{13.6}$ + 29.22 = 29.55 ins. mer.

.0480 x $\frac{528}{524}$ x $\frac{29.55}{30}$ = .0476 lbs. per cu. ft. in pipe.

$v = \sqrt{\frac{2 \times 32.16 \times 62.4}{12 \times .0476}} \times \sqrt{h} = 83.7 \sqrt{h}$

Average velocity head is .3684 ins. with kerosene

$\frac{.3684}{1.038}$ = .3555 average head in ins. of water.

$v = 83.7 \sqrt{.3555}$ = 49.9 ft. per sec. theoretical.

Average rise of holder is .488 ft. per min.

$\frac{.488 \times 16290}{60}$ = 132.5 cu. ft. per second actual amount entering holder.

132.5 x $\frac{29.52}{29.55}$ = 132.4 cu. ft. per second in pipe

Ratio from curve is .875

$\frac{132.4}{.875}$ = 151.3 cu. ft. per sec. (apparent flow).

$\frac{151.3}{3.08}$ = 49.15 ft. per second actual velocity at center of pipe.

$\frac{49.15}{49.9}$ = .986 constant of tube.

Run No.7.

This run was made on May 25th, the bottom section of the holder being used with the gas flowing into the holder. The tubes were manipulated as in the two previous runs. It was not found necessary to correct for expansion here. The average rise of the holder was .3815 ft. per min. but .381 was used in the calculations.

After all readings were taken and the gas was still flowing the following experiments were made with the tubes. With the nozzle at the center of the pipe the tube was turned through various angles and the resultant gage readings were noted.

From zero to about 10 degrees no effect upon the gauge reading was noticed but from 10° to 60° the reading gradually increased and from 60° to 90° it decreased to a small negative value. When turned 90° we would expect a zero reading because then both nozzles than act as pressure tubes.

The rubber tubes were then cross connected with No.1 pressure tube attached to No.2, differential gauge. We now had pressure from No.1 and velocity from tube No.2 acting upon gauge No.2. No.2 gauge read the same as usual and no change was noticed when tube No.1 was varied in position showing that the pressure was uniform at all sections of the pipe. With both nozzles at the center and No.2 directed against the flow, No.1 was turned through an angle of 180°. From zero to 90° gauge No.2 increased from about .26" to .40" and from 90° to 180°, goes back to about .26. This shows that there is a suction produced in the pressure tube when turned through a large angle with the gas flowing across the slit.

Calculations Run No.7.

Pressure in holder = $\frac{6.6 \times .807}{13.6} + 29.22 = 29.61$ ins. mer.

Pressure in pipe = $\frac{7.0 \times .807}{13.6} + 29.22 = 29.63$ ins. mer.

$.0480 \times \frac{29.63}{30.00} \times \frac{528}{519} = .0483$ lbs. per cu. ft. in pipe.

$$v = \sqrt{\frac{2 \times 32.16 \times 62.4}{12 \times .0483}} \times \sqrt{h}$$

$$v = 83.2 \sqrt{h}$$

Average velocity head = .242 ins. with kerosene

$\frac{.242}{1.038} = .233$ velocity head in ins. of water.

$v = 83.2 \sqrt{.233} = 40.2$ ft. per sec. (theoretical)

Average rise of holder was .381 ft. per minute.

$\frac{.381 \times 16750}{60}$ = 106.4 cu. ft. per sec. actual amount of gas entering holder.

$106.4 \times \frac{29.61}{29.66}$ = 106.3 cu. ft. per sec. through pipe.

.876 is the ratio taken from the curve.

$\frac{106.3}{.876}$ = 121.4 cu. ft. per sec. (apparent flow)

$\frac{121.4}{3.08}$ = 39.45 ft. per sec. at center (actual)

$\frac{39.45}{40.2}$ = .983 Constant of tube.

Run No.8.

Run No.8 was taken on May 25th. The holder having been filled during the previous runs, the exhauster was started, forcing the gas back into the large three section holder. The velocity was so great that gauge No.2 was set for a two inch reading to get the velocity heads at points near the center of the pipe, but readings could not be made for points near the edge of the pipe. It was therefore not feasible to draw the curves for obtaining the ratio of actual to the apparent discharge for this run.

The expansion was measured as follows:

23.78 at 2 - 57

23.77 at 3 - 6 - 30.

The expansion can be neglected because so small a reading is unreliable.

Calculations Run No.8.

Pressure in holder = $\frac{6.6 \times .807}{13.6}$ + 29.22 = 29.61 ins. mer.

Pressure in pipe = $\frac{1.56 \times .807}{13.6}$ + 29.22 = 29.31 ins. mer.

$.0480 \times \frac{528}{522} \times \frac{29.31}{30.00}$ = .04745 lbs. per cu. ft. in pipe.

$$v = \sqrt{\frac{2 \times 32.16 \times 62.4}{12 \times .04745}} \sqrt{h}$$

$$v = 84.0 \sqrt{h}$$

Average velocity head = 1.557 with kerosene

$\frac{1.557}{1.038}$ = 1.500 velocity head in ins. of water.

$v = 84.0 \sqrt{1.500}$ = 102.9 ft. per sec. (theoretical)

Average drop of holder was .987 ft. per min.

$\frac{.987 \times 16750}{60}$ = 275.8 cu. ft. per sec. the actual amount of gas entering holder.

$275.5 \times \frac{29.61}{29.31}$ = 278.2 cu. ft. per sec. in pipe.

.800 is the ratio taken from the curve

$\frac{2782}{.800}$ = 348 cu. ft. per sec. (apparent flow)

$\frac{348}{3.08}$ = 113.0 ft. per second (actual)

$\frac{113.0}{102.9}$ = 1.10 constant of tube.

Run No.9.

Run No.9 was taken on June 1 and is similar to run No.8 except that now differential gauge No.2 was set for 1 1/2 inch readings so that it was possible to take readings at all sections of the pipe. The curves drawn from the results of this run as well as run No.11, which was practically the same as run No.9 are rather peculiar in form. The first curves of both runs are similar also the last curves. But the first and last curves of the runs are different showing that there are probably stationary

waves in the pipe which slowly change in form. As will be shown later the constant of the Pitot tube is quite large at high velocities and nearly unity at ordinary velocities. If this were taken into account in drawing these curves the distortion would be even greater than shown here. It may be well to say here that the velocity at the center for the high velocity runs varied somewhat. Such variations in No.1 are evidently felt at gauge No.2. In drawing the curves, the $\sqrt{H}$ readings of No.2 were corrected by the ratio $\sqrt{H}$ average $\div$ $\sqrt{H}$ No.1.

The expansion of the gas in the holder gave the following results.

48.469 at 9 - 52 - 30

49.080 at 10 - 15 .0144 ft. per min at 10.9 A.M.

49.309 at 10 - 46 .0070 ft. per min.at 11.52 A.M.

A curve was plotted with these two values and the average expansion during the run was taken to be that obtained from this curve. The expansion was rapidly decreasing and at the average time of the run was only .003 ft. per min.

After varying the position of tube No.2, a series of readings were taken with both tubes at the center. An average of 14, $\sqrt{H}$ readings showed that gauge No.1 read 0.35% higher than No.2, both tubes and nozzles being identical.

Analysis of Gas for June 1st.

Constituents	Volume	Wts.	
C O_2	6.00 x	.1150	= .690
Illuminants	13.80 x	.0741	= 1.022
O	.80 x	.0831	= .0665
C O	25.80 x	.0729	= 1.850
H	30.24 x	.00523	= .1592

Constituents	Volume	Wts.
$C H_4$	17.28 x .0418	= .721
N_2	6.48 x .0730	= .473
		4.9817 lbs.

the weight of 100 cu. ft. at 68° F and 30 ins. of mercury.

Barometric pressure 29.48 inches of mercury.

Calculations, Run No.9,

Pressure in holder = $\frac{6.6 \times .807}{13.6}$ + 29.48 = 29.87 ins. mer.

Pressure in pipe = $\frac{1.6 \times .807}{13.6}$ + 29.48 = 29.57 ins. mer.

$.0498 \times \frac{29.57}{30.00} \times \frac{528}{531} = .04875$ lbs. per cu. ft. in pipe.

$$v = \frac{\sqrt{2 \times 32.16 \times 62.4}}{2 \times .04875} \times \sqrt{h}$$

$$v = 82.8 \sqrt{h}$$

Average velocity head = 1.446 with kerosene.

$\frac{1.446}{1.038}$ = 1.392 velocity head in ins. of water.

$v = 82.8 \sqrt{1.392} = 97.65$ ft. per sec. (theoretical)

Average drop in holder was .973 ft. per min.

$\frac{.973 \times 16750}{60}$ = 272.6 cu. ft. per second. actual amount of gas leaving holder.

$272.6 \times \frac{29.87}{29.57} = 275.6$ cu. ft. per sec. in pipe.

.820 is the ratio from the curve

$\frac{275.6}{.82}$ = 336.5 cu. ft. per sec. (apparent)

$\frac{336.5}{3.08}$ = 109.1 ft. per sec. at center (actual)

$\frac{109.1}{97.65}$ = 1.119 constant of tube.

Run No. 10.

This run is practically the same as run No.6. A thirty minute run was taken with both tubes in the center of the pipe. An average of 13 readings showed that gauge No.1 gave $\sqrt{H}$, 1.9% higher than tube No.2. There was a slight leak in the velocity side of gauge No.1 which was present until this time. The rubber tube leading to the leak was now pinched and an average of 15 readings for 15 minutes showed that gauge No.1 now read 2.0% high. Since both tubes are identical this error of 1.9% may be assumed to be the personal error because the same gauge was always read by the same person and the fluctuations in the gauge were quite considerable. The 0.1% error due to the leak may be neglected as being small.

Calculations, Run No.10.

Pressure in holder = $\frac{6.6 \times .807}{13.6} + 29.48 = 29.87$ ins. mer.

Pressure in pipe = $\frac{6.7 \times .807}{13.6} + 29.48 = 29.88$ ins. mer.

$.0498 \times \frac{528}{527} \times \frac{29.88}{30.00} = .04975$ lbs. per cu. ft. in pipe.

$v = \sqrt{\frac{2 \times 32.16 \times 62.4}{12 \times .04975}} \times \sqrt{h}$

$v = 82.0 \sqrt{h}$

Average velocity head = .6707 ins. with kerosene

$\frac{.6707}{1.038} = .5965$ velocity head in ins. of water.

$v = 82.0 \sqrt{.5965} = 66.3$ ft. per sec. (theoretical)

Average rise in holder was .636 ft. per min.

$\frac{.636 \times 16750}{60} = 176.8$ cu. ft. per sec.

actual amount of gas entering holder.

$176.8 \times \frac{29.87}{29.86} = 177.8$ cu. ft. per sec. in pipe

.872 is the ratio taken from curve.

$\frac{177.8}{.872} = 204$ cu. ft. per second (apparent)

$\frac{204}{3.08} = 66.2$ ft. per sec. (actual)

$\frac{66.2}{66.3} = .999$ constant of tube.

Calculations Run No.11.

Pressure in holder $= \frac{6.6 \times .807}{13.6} + 29.48 = 29.87$ ins. mer.

Pressure in pipe $= \frac{1.6 \times .807}{13.6} + 29.57$ ins. mer.

$.0498 \times \frac{29.57}{30.00} \times \frac{528}{531} = .04875$ lbs. per cu. ft. in pipe.

$v = \sqrt{\frac{2 \times 32.16 \times 62.4}{12 \times .04875}} \times \sqrt{h}$

$v = 32.8 \sqrt{h}$

Average velocity head is 1.478 ins. with kerosene.

$\frac{1.478}{1.038} = 1.424$ velocity head in ins. of water.

$v = 32.8 \sqrt{1.424} = 38.9$ ft. per sec. (theoretical)

Average drop of holder was .99 ft. per min.

$\frac{.990 \times 16750}{60} = 276$ cu. ft. per second, actual amount of gas leaving holder.

$276 \times \frac{29.87}{29.57} = 279$ cu. ft. per sec. in pipe.

.812 is the ratio taken from curve.

$\frac{279}{.812} = 344$ cu. ft. per sec. (apparent)

$\frac{344}{3.08} = 111.6$ ft. per sec. at center (actual)

$\frac{111.6}{98.9} = 1.13$ constant of tube.

From the results of the calculations a curve was plotted with head in inches of water as abscissae and the Pitot tube constant as ordinates. From the curve it can be seen that the constant is nearly unity for ordinary velocities. It is slightly less than unity for low velocities and increases with the velocity.

It was expected that a constant less than unity would be found but not greater. It is, however, possible for such conditions to exist. For if the gas impinging against the open velocity tube is brought to rest, a pressure is produced giving a head which is correct for the formula $v = \sqrt{2gh}$. If, however a current of gas enters the tube and is turned back on itself, a greater pressure will be produced. This is probably what happens at velocities which give a constant greater than unity.

A curve was plotted with heads in inches of water as abscissae and the theoretical velocity of air according to the formula $v = 66.7 \sqrt{h}$ as ordinates. These values were now affected by the Pitot tube constant taken from the above curve. The resulting curve gives the actual velocity of air in feet per second for various heads in inches of water.

A curve was also drawn with heads in inches of water as abscissae and per cent radius of mean velocity as ordinates. The radius of mean velocity is that radius at which the velocity if multiplied by the area of section of the pipe will give the actual volume of gas flowing. It was found for each of the curves drawn for the different runs by drawing a triangle whose area is equal to the area under the curve. The point at which the line forming the hypothenuse of the triangle intersected the curve gave the point of mean velocity. The result of the

plotted values shows that the radius of curvature is nearly a constant for all velocities. These apply to a 2½ 3/4 inch pipe and agree quite well with the result given by Mr. Threlfall who experimented with an 8 inch pipe.

In conclusion it might be said that the results show by their consistency that they are quite reliable. The curve giving the Pitot tube constant is practically within one percent of all the points plotted. The only appreciable exception is the constant found for the slowest velocity. In this case the velocity head was only .06 inch and surely an error of 5% would not be counted large for so small a head, especially when one considers the fact that the fluctuations in the gauge were more than .01 inch. Then again runs were taken with the same velocity on different days when the density of the gas had changed 4.0 percent. In one case when the velocity head was about .6 inches the results varied by a little more than one percent. In another with a head of about 3.5 inches the results were practically the same.

BAR. =

DATE 5-28-06.

TIME.	HOLDER READG.	HOLDER FT PER MIN.	TEMP.	No. 1. DIFF. HD. H	No. 1. √H	No. 1. PRES. HD.	No. 1. POSITION	No 2. DIFF. HD. H	No 2. √H	No 2. PRES. HD.	No 2. POSITION
											0-32 # Manom.
11 51	47.53		60	.93	.964	3.72	20	.31	.575	3.8	
		.765		.91	.953	3.80	"	.35	.670	3.8	31.5
11 55	44.47	.759	62	.98	.995	3.80	"	.45	.800	3.8	31
12-00	40.68	.791	62	.97	.985	3.80	"	.64	.910	3.8	30
12 05	36.78	.788	62	1.01	1.005	3.80	"	.83	.915	3.6	29
12-10	32.78	.780	62	1.00	1.00	3.70	"	.84	.915	3.7	28
12-15	28.88	.760	62	1.03	1.015	3.70	"	.93	.965	3.7	27
12-19-10	25.7		62					.96	.980		26
								.96	.980		23
								.97	.985		22
								1.00	1.00		21
								.93	.964		20
		Av-.774		.95				.91	.952		20
				UNCUPED.							
12-20				.61	.776	3.0		.78 ?	3.1		19
								.559			18
								.50			17
								.53			16
								.51			15
12-25	21.80		64	.62	.787	3.4		.49	3.2		15
								.11			14
								.39			13
12-30	18.65		64	.63	.792	3.1		.30	3.2		13
								40			12
								80			11
12-34	16.20		64								

Preliminary Run # 1.

BAR. = 29.66 DATE 5-23-05.

TIME	TEMP.	HOLDER READ'G.	HOLDER FT. PER MIN.	NO. 1. VEL. HD. H.	NO. 1. √H	NO. 1. VEL. PRESS. HD.	NO. 1. POSITION	NO. 2. VEL. HD. H	NO. 2. √H	NO. 2. PRESS. HD.	NO. 2. POSITION
							BOT. = 8				TOP = 31
11-38	60	-1.12'		.84	.916	7.4	20	.29	.538	6.4	31
							"	.425	.651		30½
			.7425				"	.455	.674		30
							"	.430	.656		29½
							"	.545	.738		29
11-42	60	1.85		.84	.916		"	.560	.748		29
							"	.535	.730		28½
							"	.585	.765		28
			.7325				"	.55	.741		27
							"	.52	.721		26
11-46	60	4.78		.84	.916		"	.70	.836		26
							"	.65	.806		24
							"	.62	.787		22
			.750				"	.74	.860		20
							"	.67	.818		19
11-51	60	8.53		.80	.894		20	.80	.894		"
				.81	.900		18				"
				.80	.894		17				"
				.80	.894		16				"
				.81	.900		15				"
			.735	.86	.927		13	.80	.894		"
				.71	.843		12	.80	.894		"
				.60	.775		11	.80	.894		"
				.56	.748		10	.80	.894		"
11-57	60	12.94		.52	.721		9½	.80	.894		"
			.735	.76	.872		9	.70	.836		"
12-01	60	15.88		.31	.557		8½	.65	.806		"
				.85	.921		20	.40	.632		31
				.84	.916		"	.50	.707		30½
			.736	.84	.916		"	.53	.728		30
				.83	.911		"	.60	.774		29½
12-6	60	19.56		.81	.900		"	.58	.761		29½
				.84	.916		"	.60	.774		29
				.84	.916		"	.68	.825		28
			.715?	.83	.911		"	.70	.836		27
				.87	.933		"	.73	.854		26
12-9-50	60	22.37		.89	.943		"	.80	.894		25

BAR. = 29.66 DATE. 5-23-05.

TIME.	TEMP.	HOLDER READ'G.	HOLDER FT. PER MIN.	No. 1. VEL. HD.	No. 1. VH	No. 1. VEL. + PRES HD.	No. 1. POSITION	No. 2. VEL. HD.	No. 2. VH	No. 2. PRES. HD.	No. 2. POSITION
12-11	60	22.88		.60	.774	8.20	R0	.60	.774	7.60	19
				.61	.781		"	.60	.774		R1
				.60	.774		"	.575	.757		R3
			.588	.62	.787		"	.56	.748		R4
				.62	.787		"	.53	.728		R5
				.62	.787		"	.53	.728		R6
12-16	60	26.82		.62	.787		"	.52	.721		R6
				.60	.774		"	.52	.721		R7
				.61	.781		"	.48	.693		R8
				.64	.800		"	.47	.685		R8½
				.65	.806		"	.46	.678		R9
			.619	.64	.800		"	.44	.663		R9½
				.65	.806		"	.43	.655		30
				.65	.806		"	.40	.632		30½
				.66	.812		"	.30	.648		31
12-23	60	30.15		.65	.806		"	.31	.557		31
				.65	.806		"	.38	.616		30½
				.67	.818		"	.41	.640		30
				.66	.812		"	.45	.671		29½
			.632	.65	.806		"	.45	.671		29
				.65	.806		"	.49	.700		R8½
				.66	.812		"	.52	.721		R8
				.65	.806		"	.55	.741		R7
12-28	60	33.31		.66	.812	8.30	"	.53	.728	7.65	R7
				.66	.812		"	.57	.755		R6
				.66	.812		"	.61	.781		R5
				.67	.818		"	.61	.781		R4
				.65	.806		"	.64	.800		R3
			.630	.65	.806		"	.65	.806		R2
				.67	.818		"	.64	.800		R1
				.64	.800		"	.63	.794		R0
				.64	.800		"	.63	.794		19
12-34	60	37.09		.65	.806		"	.63	.794		"
				.60	.774		R2	.63	.800		"
				.56	.748		R4	.64	.800		"
				.47	.685		R6	.64	.800		"
			.6325	.45	.671		R7	.65	.806		"
				.45	.671		R8	.63	.794		"
				.46	.678		R8½	.64	.800		"
				.44	.663		R9	.63	.794		"
12-42	60	42.15		.42	.648		R9½	.64	.800		"
				.42	.648		30	.63	.794		"
				.38	.616		30½	.65	.806		"
12-48 30	60			.35	.591		31½	.65	.806		"
											"

Av. = .622'/min.

Av. = .739

BAR = 29.66 # 4. DATE 5-23-05.

TIME.	TEMP.	HOLDER READ'G.	HOLDER FT. PER MIN.	No. 1. VEL. HD H	No. 1. √H	No. 1. VEL. + PRES. HD.	No. 1. POSITION	No. 2. VEL. + PRES. H	No. 2. √H	No. 2. PRES. HD.	No. 2. POSITION
2-38	62	23.1		.36	~~.721~~	~~5.1~~	20	.35	.591		19½
				.36	.600	7.6	"	.345	.587	7.0	22½
				.35	.600		"	.34	.583		24½
				.355	.591		"	.30	.548		25½
				.35	.596		"	.295	.542		27
			477	.35	.591		"	.27	.519		28
				.35	.591		"	.25	.500		29
				.36	.600		"	.23	.479		29½
				.36	.600		"	.225	.473		30
				.36	.600		"	.205	.453		30½
2-39	61.5	25.71		.355	.595		"	.21	.458		30½
				.36	.600		"	.16	.400		31
				.36	.600		"	.20	.447		30½
				.355	.596		"	.23	.479		30
				.36	.600		"	.25	.500		29½
				.36	.600		"	.28	.529		28
			450	.365	.604		"	.30	.548		27
				.365	.604		"	.325	.570		26
				.36	.600		"	.34	.583		25
				.36	.600		"	.345	.587		23
				.36	.600		"	.36	.600		21
				.365	.604		"	.365	.604		19
2-46	61	28.56		.365	.604		"	.375	.612		19
				.34	.583		21	.355	.596		"
				.31	.557		23	.355	.596		"
				.29	.538		24	.365	.604		"
			453	.255	.504		25	.36	.600		"
				.235	.484		26	.36	.600		"
				.22	.469		27	.36	.600		"
2 51	61	31.125		.21	.458		27	.365	.604		"
				.22	.469		28	.36	.600		"
				.20	.447		28½	.37	.608		"
				.20	.447		29	.37	.608		"
			455	.20	.447		29½	.37	.608		"
				.19	.536		30	.38	.616		"
				.19	.536		30½	.38	.616		"
				.18	.424		31	37	.608		"
				.13	.360		31½	33	.575	OVER.	"

BAR. = 29.66

DATE 5-23-05.

TIME	TEMP.	HOLDER READG	HOLDER FT. PER MIN.	No. 1. VEL. HD H	No. 1. √H	No. 1. VEL. x PRES HD.	No. 1. POSITION	No. 2. VEL. HD H	No. 2. √H	No. 2. PRES. HD.	No. 2. POSITION
2-56	61	33.40		.13	.360		31½	.38	.616	7.0	19
				.19	.436		31	.33	.574		"
				.23	.479		30½	.35	.592		"
				.25	.500		30	.36	.600		"
				.23	.479		29½	.37	.608		"
			450	.21	.458		29	.375	.612		"
				.225	.474		28½	.37	.608		"
				.23	.479		28	.37	.608		"
				.27	.520		27	.365	.604		"
3-01	61	35.65		.215	.464		27	.30	.548		"
				.25	.500		26	.38	.616		"
				.28	.529		25	.36	.600		"
			452	.305	.552		23	.365	.604		"
				.33	.574		21	.36	.600		"
				.35	.592		19¾	.37	.608		"
3-07		38.36	44				"				"
3-09		39.24		.33	.574	7.6	"	.305	.552		"
			443	.355	.596		"	.35	.592		"
3-12		40.57	46	.295	.543		"	.305	.552		"
13	61	41.03	45	.34	.583		"	.33	.574		"
14		41.48	435	.33	.574		"	.34	.583		"
15		41.915	453	.29	.538		"	.33	.574		"
22		45.085	458				"	.35	592		"
27	61	47.375						.33	574		"

Av. = 450'/MIN.

Av. .596

BAR. = 29.22 *5. DATE 5-26-05

TIME.	TEMP.	HOLDER READ'G.	HOLDER FT. PER MIN.	No. 1. VEL. HD H	√H	VEL'T PRES HD.	POSITION	No. 2. VEL. HD. H.	√H	PRES. HD.	POSITION
10-45	66	-3.24		.075	.274	5.0"	CENTER	.077	.277	5.2"	19
			.252	.077	.277		"	.077	.277		20
10-50	65	-1.98		.077	.277		"	.082	.286		21
				.078	.279		"	.078	.279		22
			.246	.080	.283		"	.077	.277		23
				.081	.285		"	.077	.277		23
10 55	64.5	-0.75		.081	.285		"	.076	.276		23
				.080	.283		"	.073	.270		24
			.252	.078	.279		"	.075	.274		25
11 00	64.5	0.51		.080	.283		"	.077	.277		25
				.081	.285		"	.074	.272		26
				.075	.274		"	.074	.272		27
				.075	.274		"	.074	.272		28
			.261	.078	.279		"	.070	.265		29
				.081	.285		"	.066	.257		29½
				.080	.283		"	.067	.259		30
11-05	64.8	1.815		.079	.281		"	.062	.249		30
				.078	.279		"	.057	.239		30½
				.077	.277		"	.044	.210		31
			.250	.078	.279		"	.047	.217		30½
				.077	.277		"	.053	.230		30
11-10	64.0	3.065		.081	.285		"	.057	.239		30
				.080	.283		"	.062	.249		29½
			.241	.078	.279		"	.074	.272		29
				.078	.279		"	.077	.277		28
11-15	64.0	4.27		.079	.281		"	.077	.277		27
				.080	.283		"	.080	.283		27
			.2616	.081	.285		"	.084	.290		26
11-20	63.8	5.578		.080	.283		"	.082	.286		25
				.078	.279		"	.082	.286		25
				.079	.281		"	.080	.283		23
"				.078	.279	5.3"	"	.081	.285	5.24"	21
								.082	.286		19

6.627' at 11.25
6.668 " 11.45
E_{y_n} = .002'/MIN.
Av. .252 - .002 = .250'/MIN.

Av. .2805

BAR. = 29.22 #8 DATE 5-25-05

TIME	TEMP.	HOLDER READ'G.	HOLDER FT. PER MIN.	No. 1. VEL. HD H	No. 1. √H	No. 1. PRES.+VEL. HD.	No. 1. POSITION	No. 2. VEL. HD H	No. 2. √H	No. 2. PRES. HD.	No. 2. POSITION
11 58	67	10.27		.355	.596	6.0	CENTER	.34	.583	5.6	19
			.484	.33	.574		"	.31	.556		21
12-5	65.1	13.66		.37	.608		"	.34	.583		23
				.375	.612		"	.32	.566		25
				.38	.616		"	.31	.557		26
			.496	.36	.600		"	.30	.548		27
				.38	.616		"	.29	.538		28
				.36	.600		"	.27	.519		29
12-10	63.2	16.14		.37	.608	6.0	"	.25	.500		29½
				.37	.608		"	.24	.490	5.6	30
				.375	.612		"	.22	.469		30½
				.375	.612		"	.155	.394		31
			.490	.37	.608		"	.22	.469		30½
				.38	.616		"	.23	.479		30
				.375	.612		"	.245	.495		29½
				.37	.608		"	.275	.524		29
				.37	.608		"	.29	.538		28
12-15	63	18.59		.38	.616		"	.30	.548		27
				.375	.612		"	.32	.568		26
				.37	.608		"	.33	.574		25
			.488	.37	.608		"	.34	.583		23
				.35	.592	6.0	"	.34	.583	5.6	21
				.365	.604		"	.355	.596		19
12-20	61.8	21.03		.365	.604		"	.36	.600		19

AV. = .607

R1872' AT 12-25
R1900 " 12-55
DIF. = .0009' FT/MIN.
AV. = .489 — .0009 = .488

BAR. - 29.22 #17. DATE 5-26-05

TIME.	TEMP.	HOLDER READ'G	HOLDER FT. PER MIN	No. 1. VEL. HD. H.	No. 1. √H.	No. 1. PRES'VEL HD.	No. 1. POSITION	No. 2. VEL. HD. H.	No. 2. √H.	No. 2. PRES. HD.	No. 2. POSITION
1-02	59.2	22.98		.235	.496	7.3	CENTER	.23	.479	7.05	19
				.230	.484		"	.23	.479		21
				.24	.479		"	.23	.479		23
				.245	.495		"	.22	.469		25
			.375	.25	.490		"	.205	.452		26
				.255	.500		"	.195	.441		27
				.22	.505 .469		"	.19	.436		28
				.245	.495		"	.175	.418		29
				.24	.490		"	.165	.406		29½
1-10	59.0	25.98		.245	.495		"	.17	.412		29½
				.25	.500		"	.155	.393		30
				.245	.495		"	.14	.374		30½
			.384	.25	.500		"	.10	.316		31
				.25	.500		"	.10	.316		31
				.25	.500		"	.135	.367		30½
				.25	.500		"	.16	.400		30
1-15	59.0	27.90		.25	.500		"	.16	.400		30
				.24	.490		"	.16	.400		29½
			.386	.24	.490		"	.175	.418		29
				.23	.479		"	.195	.441		28
				.21	.458		"	.20	.447		27
1-20	59.0	29.83		.25	.500		"	.215	.463		26
				.245	.495		"	.22	.469		25
			.389	.255	.505		"	.23	.479		23
				.25	.500		"	.24	.490		21
1-25	59.0	31.775	.379	.25	.500		"	.24	.490		19
1-30	58.8	33.67	.384	.24	.490		"	.24	.490		19
1-35	58.5	35.59	.3795	.235	.484	7.3	"	.23	.479	7.0	19
1-45		39.385		.25	.500		"				

Av. = 381'/min.

Av. = .492

BAR. - 29.22 #8. DATE 5-25-05

TIME.	TEMP.	HOLDER READ'G	HOLDER FT. PER MIN.	No. 1. VEL. HD. H	No. 1. √H	No. 1. VEL. + PRES. HD.	No. 1. POSITION	No. 2. VEL. HD. H	No. 2. √H	No. 2. PRES. HD.	No. 2. POSITION
2-32 30	59.5	45.16		1.54	1.240	3.09	CENTRE	1.46	12.08	1.56	19
				1.515	1.230		"	1.39	11.79		21
				1.53	1.237		"	1.28	11.31		23
			.976	1.51	1.229		"	1.07	10.34		25
				1.52	1.233		"	1.08			
				1.56	1.249		"				
240		37.84		1.58	1.257		"				
				1.60	1.265		"				
				1.61	1.269		"				
			1.008	1.65	1.284		"				
				1.68	1.296		"				
2-45	62	32.80		1.58	1.257		"				
				1.56	1.249		"				
				1.58	1.257		"				
			.983	1.50	1.225		"	1.00	1.00		26
				1.50	1.225		"	.96	.980		27
				1.49	1.221		"	.95	.975		28
2-51		26.90		1.51	1.229		"	.93	.964		29
				1.515	1.245		"	.97	.985		30
			.990	1.58	1.257		"	.90	.949		31
				1.57	1.253		"				
2-54	63	23.93									

2.57 at 2.57
3.6-30
2.77 "
Con. .001 / MIN.
AV = .987

AV = 1.248

#9.

BAR. - 29.48 DATE. 6-1-'05.

TIME.	TEMP.	HOLDER READ'G	HOLDER FT. PER MIN.	No. 1. VEL. HD. H	No. 1. √H	No. 1. VEL.+PRES. HD.	No. 1. POSITION	No. 2. VEL. HD. H	No. 2. √H	No. 2. PRES. HD.	No. 2. POSITION
11.8	70	46.37		1.72	1.311	3.6	CENTER	1.00	1.00	2.2	31
				1.70	1.304		"	1.05	1.025		30½
				1.70	1.304		"	1.10	1.049		30
			1.03R	1.74	1.309		"	1.15	1.072		29½
				1.69	1.300		"	1.13	1.063		29
				1.64	1.281		"	1.00	1.00		28½
11.12	70	42.24		1.55	1.245		"	.95	.975		28
				1.54	1.241		"	1.00	1.00		27
				1.52	1.233		"	1.05	1.025		26
				1.46	1.209		"	1.10	1.049		25
			.975	1.42	1.191		"	1.20	1.095		24
				1.44	1.200		"	1.25	1.118		23
				1.44	1.200		"	1.35	1.162		21
				1.44	1.200		"	1.47	1.212		19
11.16	70	38.34		1.40	1.183		"	1.45	1.204		19
				1.42	1.192		"	1.35	1.162		21
				1.40	1.183		"	1.20	1.095		23
				1.39	1.179		"	1.00	1.00		25
				1.37	1.170		"	.90	.949		26
			.953	1.39	1.179		"	.88	.938		27
				1.39	1.179		"	.87	.933		28
				1.39	1.179		"	.87	.933		29
				1.36	1.166		"	.87	.933		29½
				1.38	1.175		"	.90	.949		30
11.22	71.5	32.62		1.35	1.162		"	.85	.922		30½
				1.36	1.166	3.6	"	.80	.844	2.2	31
											19½
			.980	1.424	1.193		"	1.403	1.187		"
							"				"
							"				"
11.27	72	27.72					"				"
							"				"
							"				"
			.935	1.353	1.163		"	1.351	1.162		"
							"				"
							"				"
11.31	73	23.98					"				"
			Av. = .970 +.003 = .973		Av. = 1.202						

BAR. = 29.48 DATE 6-1-'05.

TIME.	TEMP.	HOLDER READ'G	HOLDER FT. PER MIN.	NO. 1. VEL. HD. H	NO. 1. √H	NO. 1. VEL+PRES HD.	NO. 1. POSITION	NO. 2. VEL. HD. H	NO. 2. √H	NO. 2. PRES. HD.	NO. 2. POSITION
1-17	68.2	23.18		.67	.818	7.4	CENTER	.29	.538	6.4	31
				.67	.818		"	.40	.632		30*
				.66	.812		"	.45	.671		30
				.66	.812		"	.46	.678		29*
				.66	.812		"	.48	.693		29
			.624	.66	.812		"	.51	.714		28
				.67	.818		"	.55	.742		27
				.67	.818		"	.57	.755		26
				.66	.812		"	.62	.787		25
				.66	.812		"	.62	.787		24
1-22	67.5	26.30		.67	.818		"	.65	.806		23
				.67	.818		"	.65	.806		21
				.66	.812		"	.65	.806		19
				.67	.818		"	.65	.806		21
				.66	.812		"	.64	.800		23
				.68	.825		"	.64	.800		24
			.642	.66	.812		"	.60	.775		25
				.67	.818		"	.60	.775		26
				.67	.818		"	.57	.755		27
				.66	.812	7.4	"	.53	.728	6.7	28
				.70	.837		"	.50	.707		28*
				.65	.806		"	.49	.700		29
1-27	67.	29.51		.66	.812		"	.47	.685		29*
				.67	.818		"	.42	.648		30
			.634	.66	.812		"	.40	.632		30*
1.32	67.	32.68		.67	.818		"	.285	.533		31
				.670	.818		"	.650	.806		19*
			.639	.6766	.8225		"	.650	.806		"
1.37	66.5	35.875					"				"
			.635	.6675	.817	PINCHED	"	.645	.803		"
1.42	66.5	39.05					"				"
			.646	.675	.8215		"	.645	.803		"
1.47	67.	42.28					"				"
			.636	.678	.8235		"	.6466	.8045		"
1.52	66.3	45.46					"				"
			.632	.672	.820		"	.646	.8038	6.7	"
1.57	66.5	48.62	AV. = .636		AV. = .819						

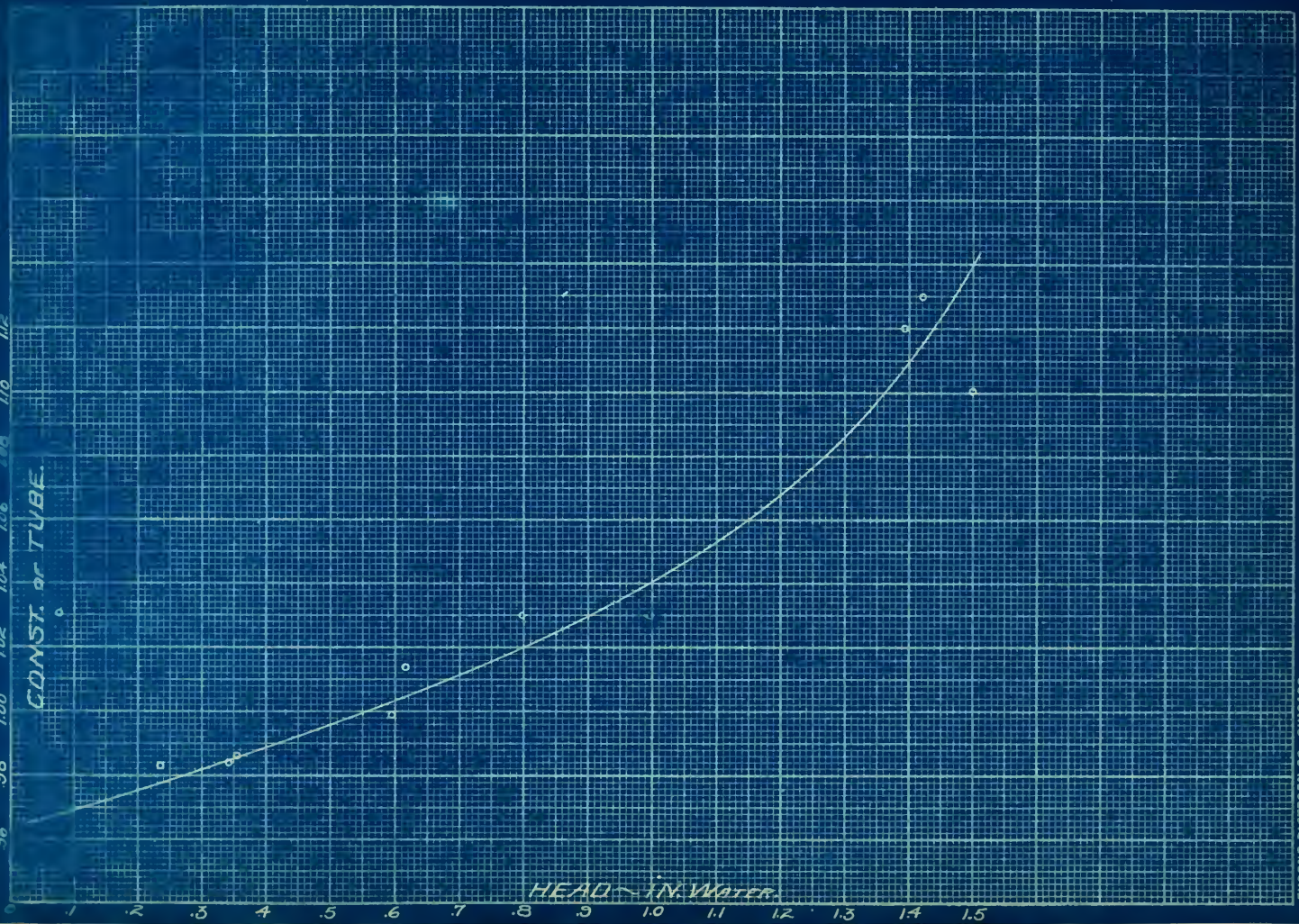
Exp = 49.695 AT 2-5-45 / 49.701 " 2-26-45 / .0003'/MIN. :: NEGLECT.

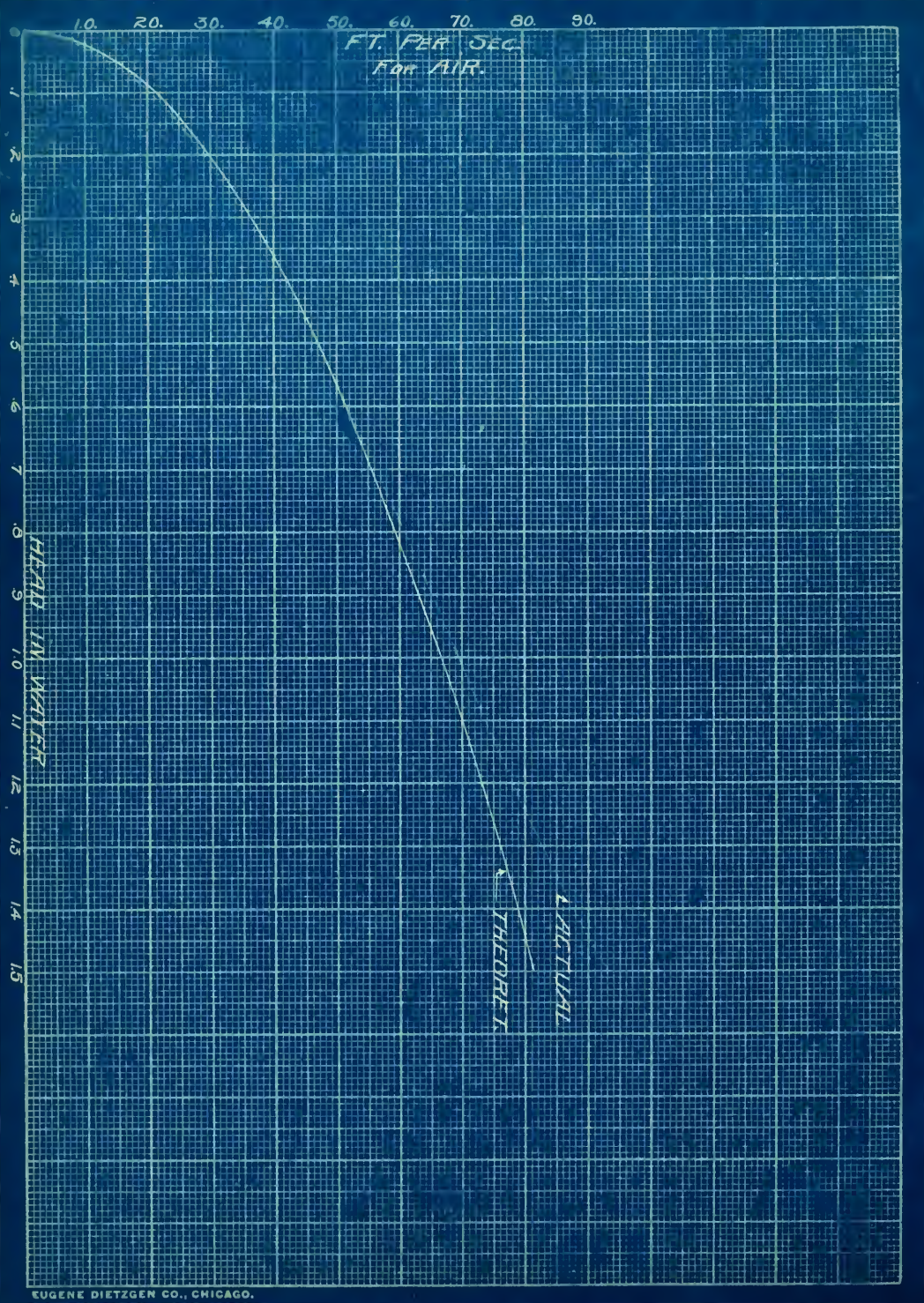
BAR - 2948 # 11. DATE 6-1-06

TIME	TEMP.	HOLDER READ'G	HOLDER FT. PER MIN.	No. 1. VEL. HD.	$\sqrt{H}$	VEL. PRES. HD.	POSITION	No. 2. VEL. HD. H.	$\sqrt{H}$	PRES. HD.	POSITION
2-31	68	4718		1.49	1.221	3.1	CENTER	.85	.922	1.6	31
				1.53	1.235		"	.90	.949		30½
				1.45	1.212		"	.95	.975		30
			.982	1.47	1.212		"	.96	.980		29½
				1.49	1.221		"	.96	.980		29
				1.51	1.229		"	.97	.985		28
				1.52	1.233		"	.99	.995		27
2-36	69.5	4227		1.56	1.249		"	1.02	1.01		26
				1.52	1.233		"	1.12	1.058		25
				1.50	1.225		"	1.25	1.118		24
				1.51	1.229		"	1.28	1.131		23
				1.48	1.216		"	1.30	1.140		21
				1.49	1.221		"	1.50	1.225		19
				1.48	1.216		"	1.30	1.140		21
2-40			.978	1.48	1.216		"	1.28	1.131		23
				1.46	1.208		"	1.25	1.108		24
				1.46	1.208		"	1.10	1.049		25
				1.47	1.212		"	.98	.990		26
				1.47	1.212		"	.93	.964		27
				1.52	1.233		"	.95	.975		28
2-41	70.5	3738		1.55	1.245		"	.97	.985		29
				1.56	1.249		"	.99	.995		29½
				1.53	1.237		"	1.00	1.00		30
			.9983	1.53	1.237		"	1.00	1.00		30½
				1.51	1.229		"	.87	.933		31
				1.51	1.229		"				
				1.52	1.233		"				
2-47		3139		1.52	1.233		"				
				1.50	1.225		"				
				1.52	1.233		"				
				1.53	1.237		"				
				1.53	1.237		"				
			1.002	1.52	1.233		"				
				1.52	1.233		"				
				1.49	1.221		"				
				1.51	1.229		"				
				1.51	1.229		"				
2-52	72	2638		1.47	1.212		"				
AV OF 9 READ'GS 2-55½	72.5	2294	.983	1.467	1.211		"	1.432+	1.197		19½

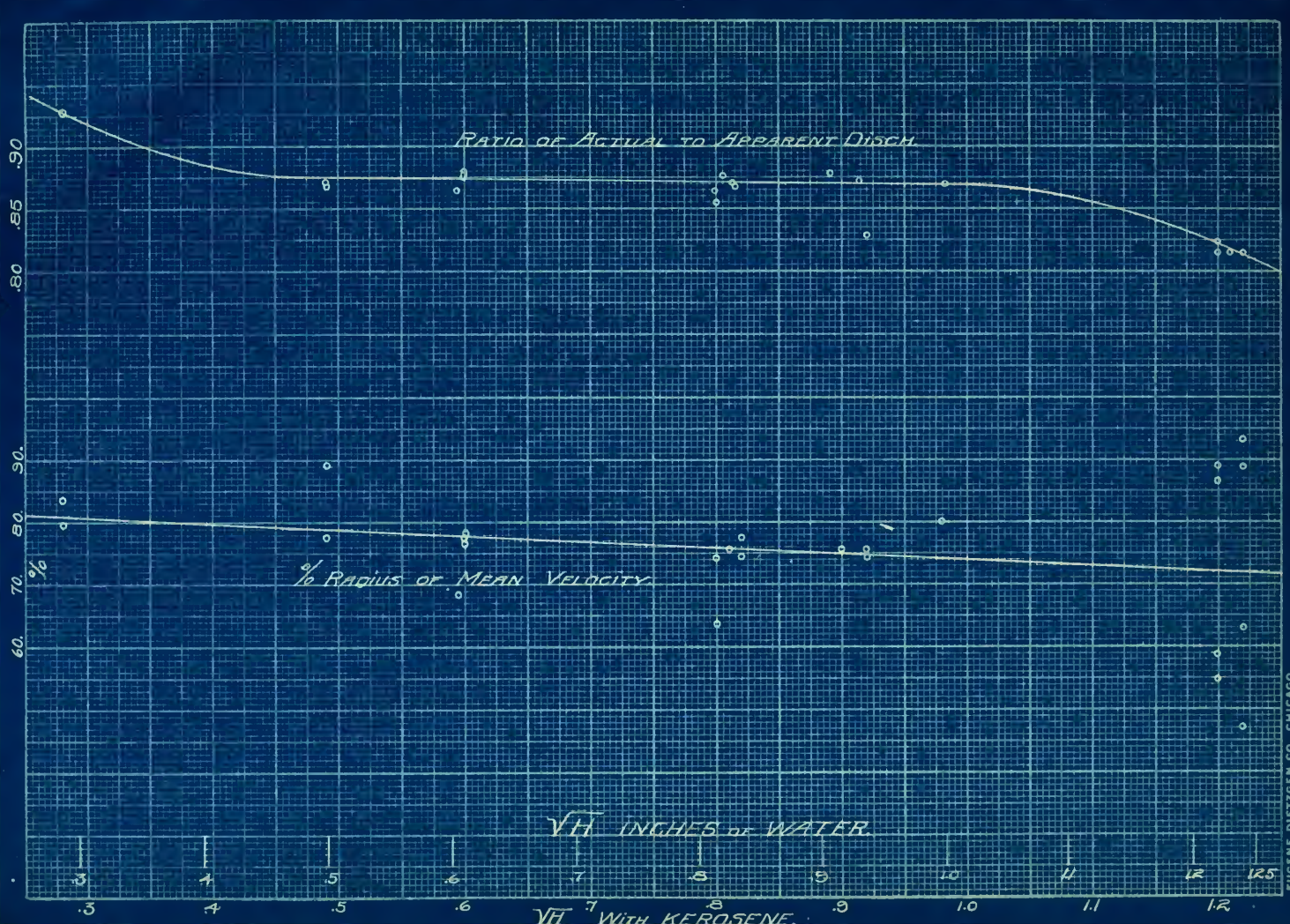
AV. = .990

AV = 1.2166


CONST. of TUBE.
.96
.98
1.00
1.02
1.04
1.06
1.10
1.12
HEAD - IN. WATER.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
EUGENE DIETZGEN CO., CHICAGO.



EUGENE DIETZGEN CO., CHICAGO.


Ratio of Actual to Apparent Disch.
.90
.85
.80
90.
80.
70.
60.
% Radius of Mean Velocity
√H Inches of Water.
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
√H With Kerosene.
Eugene Dietzgen Co., Chicago.